ENHANCED OIL BIODEGRADATION ON AN ARCTIC SHORELINE

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INTRODUCTION

As a consequence of the oil industry's expansion into the Arctic, countermeasures against oil pollution on these shorelines have to be adapted. The following requirements must be met: limited accessibility for heavy machinery and/or manpower; and large capacity for treatment of oily wastes in operationally unaccessible areas. These demands may seem impossible to meet. Consequently, it may be desirable to let the natural environment itself clean the oil-polluted beach. Wave action may clean the intertidal areas, however oil deposited in the supralittoral zone is practically unaffected by the sea. The only physical process that may take place is burial of the oil by shoreline processes. In this context, the possibility of developing techniques to accelerate oil biodegradation in situ, combined with the creation of a dry, non sticky, soil surface of the oil-polluted supralittoral zone, are of interest. Combining these two demands in one technique ensures that the acute threat of pollution to birds and higher animal life is diminished; over a period of time, nature will get rid of the oil contamination as such.

To study the enhancement of biodegradation and creating a dry, non-sticky, soil surface, test plots at Cape Hatt, Baffin Island, Canada, were established as a part of the Baffin Island Oilspill Project. These plots were treated with various combinations of fertilizers, organic sorbents and land tilling.

METHODS AND EXPERIMENTAL DESIGN

Methods of the enumeration of heterotrophic bacteria (MPN), estimates of total heterotrophic respiration and the study of soil fauna populations have been published by Eimhjelleh et al., (1981). Total oil content is estimated by CCl_4 extraction. Each sample for oil extraction is a mixed sample of 25 subsamples. Each estimate of oil content is based on five replicates from this mixed sample. Total nitrogen content in soil (including NO_3^-) is analyzed according to Bestyrerne ved Landbruksjemiske kontrollstasjoner (1959). The technique for oiling the beach is given by Woodward-Clyde Consultants (1981). Fertilizers were added with a lawn fertilizer machine.

In 1980, two test plots were established (Eimhjellen et al., 1981). In 1981, seven new plots were established. These are summarized in Table 1.

TABLE 1 EXPERIMENTAL DESIGN. ENHANCED BIODEGRADATION OF OIL ON SHORELINE 102, CAPE HATT.

Exp. No.	Oil Type and Amount	Treatment	Year
102 A	Emulsified oil 20 L/m^2	None	Aug 23 1980
102B	Aged oil 10 L/m^2	None	Aug 23 1980
102C	No oil. Control	None	1980
102 D_0	Emulsified oil 20 L/m^2	Organic sorbent	Aug 1 1981
102 D_1	Emulsified oil 20 L/m^2	BP solidifying agent	Aug 1 1981
102 D_2	Emulsified oil 20 L/m^2	BP solidifying agent manually cleaned	Aug 1 1981
102 E	Emulsified oil 20 L/m^2	0.4 kg/m^2 fertilizer added. Oil tilled into soil.	Aug 1 1981
102 F	Emulsified oil 20 L/m^2	None. Control	Aug 1 1981
102 G	Emulsified oil 20 L/m^2	0.04 kg/m^2 fertilizer added.	Aug 1 1981
102 H	Emulsified oil 20 L/m^2	0.4 kg/m^2 fertilizer added.	Aug 1 1981

To enhance biodegradation, a commercial fertilizer was added to the test plots. Amounts of fertilizer added to test plot 102 E, G and H are shown in Table 2.

TABLE 2 AMOUNT OF FERTILIZER ADDED (g/m^2)

	Agent						
Plot	N	P	K	Mg	S	Ca	B
102 G	6.4	2.6	4.8	0.5	0.6	1.2	0.01
102 E 102 H	64.0	26.4	47.6	4.8	6.4	12.0	0.08

The amount of sorbent to be added was calculated from oil deposited, to oil volume ratio 1:1.

RESULTS AND DISCUSSION

Initial conditions for oil biodegradation in the different test plots are shown in Table 3. All plots contained somewhere between 35-50 g oil/kg soil in the upper cm of the soil. As can be seen, oil on plot 102E was tilled into the soil; an increased oil content was detected deeper in the soil.

The real C/N and C/P ratios that affected total heterotrophic respiration and microbial growth cannot be detected by these analytical results. These processes are dominated by the activity on the oil film surface. The effects of adding fertilizers were masked to some extent by variations in the background level of total nitrogen in the soil. Relatively, the C/N and C/P ratios can however be anticipated by comparing the amount of nitrogen added to the different oil.

TABLE 3 INITIAL CONDITIONS OF OIL BIODEGRADATION. OIL AND NITROGEN CONTENT (BESTYRERNE, 1959) IN THE SOIL OF BEACH 102 (1981).

	Surface 0-5 cm		Subsurface 0-10 cm	
Plot	g oil/kg soil	mg N/kg soil	g oil/kg soil	mg N/kg soil
A	51.0 -	129 - 151	1.7 -	92 - 93
B	46.2 -	130 - 131	29.4 -	72 - 82
D_0	48.5 ± 1.6	125 - 177	4.3 ± 0.2	69 - 80
$D_{1,2}$	37.3 ± 0.9	163 - 194	9.6 ± 0.4	163 - 194
E	16.2 ± 0.2	310 - 343	11.4 ± 0.1	245 - 245
F	35.2 ± 0.4	106 - 109	5.9 ± 0.2	6 - 8
G	39.3 ± 0.3	237 - 244	6.9 ± 0.2	70 - 74
H	49.1 ± 0.5	178 - 190	9.6 ± 0.3	76 - 81

MICROBIOLOGY

The development in the microbial community of the different test plots is shown in Tables 4 and 5. As can be seen, a rapid increase in oil degraders occurred in all test plots. The total heterotrophic community also increased in comparison to the unoiled test plot 102C. The response of the microflora can best be compared by evaluating the results from the different plots on Aug. 17 1981 (Table 5). The oil degrading bacteria responded to the different ways of treating the oil. The plots with increasing content of oil-degrading bacteria can be ranged in the sequence from 102 F - 102 D - 102 G - 102 E - 102 H.

Based on the microbial data, the addition of large amounts of fertilizer (102 H0 does pay off. Tilling the oil into the soil did not enhance microbial growth to a further extent (102 E). Land tilling did, however, create a non-sticky surface. The use of a sorbent and a low load of fertilizers increased the microbial populations but not to the same extent (102 D and G).

TABLE 4 MICROBIAL DEVELOPMENT IN THE SURFACE LAYER (0-2 cm) OF UNTREATED OIL TEST PLOTS. Cells/mL soil x 10^{-4} by MPN-method; TH = total number of heterotrophic bacteria; OD = number of oil-degrading bacteria. Samples marked with * are assessed after only 6 days of incubation.

	Plot 102 A		Plot 102 B		Plot 102 C	
Date	TH	0	TH	OD	TH	OD
Aug. 26 1980	1.5	0.015	0.75	0.02	0.45	0
Aug. 31 1980	950	75	2.5	2.5	1.5	<0.01
Sept. 9 1980	*4 500	1 500	45	9.5	0.025	<0.01
Aug. 1 1981	730	0.073	280	0.28	1.3	<0.01
Aug. 17 1981	4 400	13	2 800	7.3	130	<0.01

TABLE 5 MICROBIAL DEVELOPMENT IN 1981 TEST PLOTS. Cells/mL. soil 10^{-4} by MPN-method; TH = total number of heterotrophic bacteria; OD = oil degrading bacteria.

	Plot 102 D		Plot 102 E		Plot 102 F		Plot 102 G		Plot 102 H	
Date	TH	OD	TH	OD	TH	OD	TH	OD	TH	OD
Aug. 1 1981										
0-2 cm	7.3	0.01	280	0.01	7.3	0.01	13	0.01	4.4	0.01
5-10 cm	-	-	-	-	-	-	-	-	-	-
Aug. 5 1981										
0-2 cm	1 300	0.73	73	0.28	73	28	730	2 800	73	2.8
5-10 cm	2.8	1.3	4.4	0.07	3 130	28	73	7.3	280	7.3
Aug. 17 1981										
0-2 cm	7 300	28	730	730	730	0.73	280 000	73	73 000	7 300
5-10 cm	2 800	13	1 300	730	1 300	28	130 000	1 300	73 000	7 300

INVERTEBRATE FAUNA

The Collembola are the dominating invertebrates is this type of shoreline sediments. Even this systematic taxon is very impoverished. Only two species are common, Archisotoma besselsi (Pacard) and Hypogastrura aff. matura (Mac Nam). Population activity, based on data from pitfall traps, shows these two species to inhabit the shoreline with fairly stable populations (Table 6).

TABLE 6 COLLEMBOLA AT CAPE HATT BEACH 102 C, SUPRALITTORAL ZONE (Numbers per trap per 24 hours)

Species	1980-08-02	1980-09-05	1981-08-05	1981-08-30
A. besselsi	108 ± 20	145 ± 35	190 ± 45	150 ± 40
H. matura	-	-	40 ±	50 ± 25

Both aged and emulsified oil were found to kill the populations totally. After 1 year (102A and 102B), the populations were not reestablished. The only treatment that did not totally eliminate these invertebrates was the one given to test plot 102E, where oil was tilled into the sediments. Here the population of A. besselsi was approximately 10%, and H. matura approximately 4%, of the normal level.

TOTAL HETEROTROPHIC RESPIRATION

The rates of heterotrophic respiration at the different plots are shown in Tables 7 and 8. Rates of respiration are significantly increased by adding fertilizers. There is no significant difference (10% level) between the tilled plot 102 E and the other plot 102 H. Both have significantly higher bacterial counts than the plot with a low load of fertilizer (102 G); the carbon dioxide production was approximately five times the rates recorded in the control plot. Respiration in the plot with sorbent was decreased compared to normal rates. This can not, at present, be satisfactorily explained.

TABLE 7 TOTAL HETEROTROPHIC RESPIRATION (mg C/m^2/h), Beach 102

	1980									1981					
	Aug. 25			Aug. 30			Sept. 6			July 25			Aug. 20		
Plot	$\bar{X}$	SE	n	$\bar{X}$	SE	n	$\bar{X}$	SE	n	$\bar{X}$	SE	n	$\bar{X}$	SE	n
102 A	28	6	4	34	2	2	12	2	2	36	4	38	24	4	27
102 B	17	4	3	35	6	4	21	8	4	34	5	27	40	7	16
102 C	13	5	3	13	13	4	18	12	4	18	2	31	-	-	-

TABLE 8 TOTAL HETEROTROPHIC RESPIRATION (mg C/m^2/h), Beach 102

	Aug. 4-5			Aug. 23-24		
Plot	$\bar{X}$	SE	n	$\bar{X}$	SE	n
102 D	21	2	42	13	3	21
102 E	41	5	32	133	17	20
102 F	20	2	27	30	7	14
102 G	21	3	26	69	8	16
102 H	49	8	24	156	18	16

The rates of respiration should not be taken as exact figures for the in situ production of CO_2 in undisturbed beach sand. They serve the purpose for comparing the heterotrophic activity from test plot to test plot. It is obvious that the temperature development inside the respiration chambers is different from that outside. An example of the temperature profiles inside the respiration chambers compared with the natural temperature development is shown in Figure 1. The average temperature profile at beach 102 is shown in Figure 2. The daytime temperature range when the respiration rates were recorded were between 5.7° C and 10.0° C, Aug. 4-5, 1981, and between 6.3° C and 10.7° C, Aug. 23-24, 1981. The variations in respiration rates caused by such relatively small variations in temperature could not be singled out from other environmental factors affecting the heterotrophic respiration at the different sites. The data are however comparable to rates of in situ respiration reported from oiled and unoiled plots in Alaska (Sparrow et al., 1978).

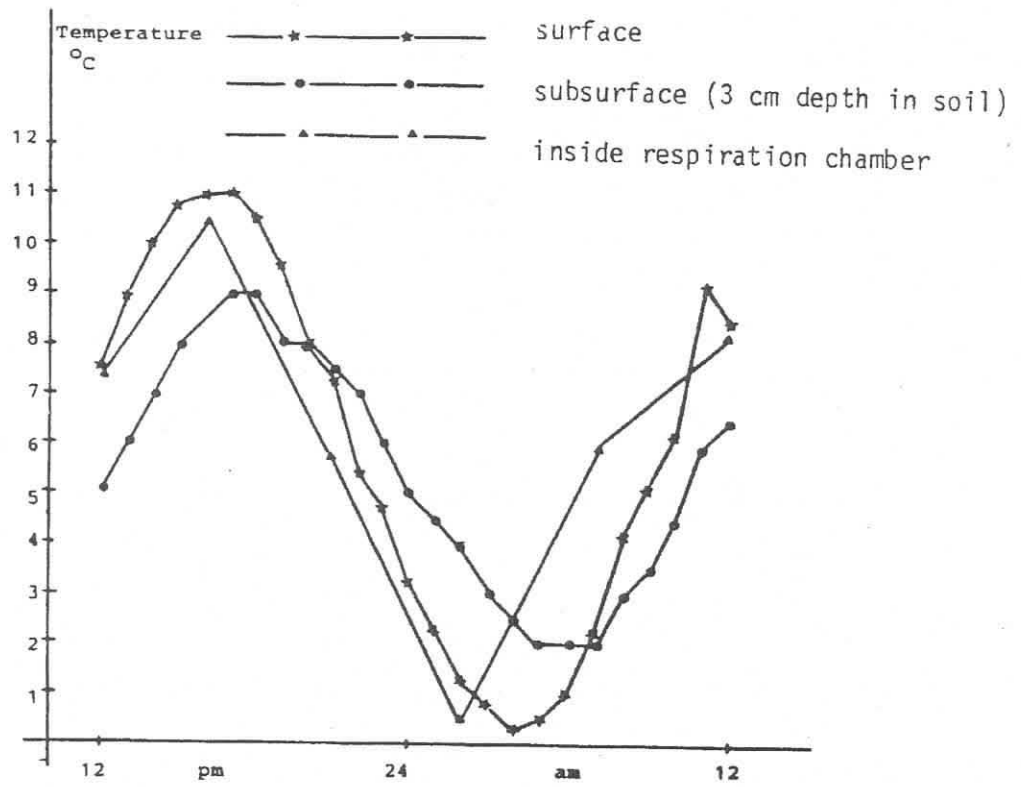

FIGURE 1 TEMPERATURE DEVELOPMENT AT PLOT 102 F AUG. 14-15, 1981.

The treatment of oil on shorelines with the BP solidifying agent created a non-sticky soil surface. Total heterotrophic respiration in this plot was recorded to 86 ± 9 mg $C/m^2/h$ on Aug. 8. On 19, the corresponding rate was 63 ± 8 mg $C/m^2/h$. These rates are higher than in the control

~~in the control~~ plot (Table 8). This treatment made it possible to quite easily manually pick up roughly 50% of the oil from the beach surface. After manually cleaning the plot, the respiration rate of the soil increased to 81 ± 8mg $C/m^2/h$.

TOTAL OIL DECOMPOSITION

The change in total oil with time for the various plots is shown in Tables 9 to 11. Over a time span of 2 years, total oil decomposition is greater in the plot with aged than in the plot with emulsified oil (Tables 9 and 10). The observation during the summer of 1981 was of too short duration to anticipate any significant change in total oil content of the plots established this year. An adaptation of the microflora also has to take place before any significant change can occur during the second summer season.

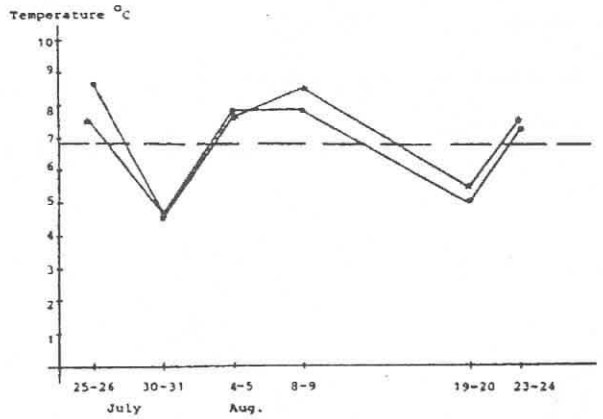

Figure 2. Mean temperature development at beach 102 the 1981 summer.

surface

3 cm depth

TABLE 9 TOTAL OIL CONTENT IN PLOT 102 (g OIL/kg SOIL).

	1980			1981					
	Aug. 1			July 24			Aug. 25		
Depth in Soil	$\bar{X}$	SE	n	$\bar{X}$	SE	n	$\bar{X}$	SE	n
0- 5 cm	51.0	-	1	51.8	0.8	5	44.3	1.9	5
5-10 cm	17.0	-	1	23.2	0.6	5	12.9	0.2	5

TABLE 10 TOTAL OIL CONTENT IN PLOT 102 B (g oil/kg soil)

	1980			1981					
	Aug. 1			July 24			Aug. 25		
Depth in Soil	$\bar{X}$	SE	n	$\bar{X}$	SE	n	$\bar{X}$	SE	n
0-5 cm	46.2	-	1	42.8	0.3	5	19.1	0.3	5
5-10 cm	29.4	-	1	18.2	0.4	5	19.1	0.1	5

TABLE 11 TOTAL OIL CONTENT OF THE DIFFERENT TEST PLOTS 1981 (g oil/kg soil)

		Aug. 1		Aug. 25	
Plot	Depth	$\bar{X}$	SE	$\bar{X}$	SE
102 D_0	0-5 cm	49.5	1.6	51.6	0.9
	5-10 cm	4.3	0.2	2.3	0.1
102 D_1	0-5 cm	37.3	0.9	35.1	0.8
	5-10 cm	9.6	0.4	6.2	0.6
102 D_2	0-5 cm	37.3	0.9	19.2	0.9
	5-10 cm	9.6	0.4	6.4	0.2
102 E	0-5 cm	16.2	0.2	15.4	0.4
	5-10 cm	11.4	0.1	13.9	0.3
102 F	0-5 cm	35.2	0.4	39.7	0.4
	5-10 cm	5.9	0.2	9.6	0.3
102 G	0-5 cm	39.3	0.3	36.9	1.2
	5-10 cm	6.9	0.2	4.8	0.2
102 H	0-5 cm	49.1	0.5	50.2	0.4
	5-10 cm	9.6	0.3	6.0	0.1

CONCLUDING REMARKS

These studies show that the heterotrophic respiration of oil slicks in the supralittoral zone of arctic beaches can be enhanced up to about five times the normal rates of beach sediments. It is also shown than the microbiological community responds to heavy loads of fertilizers. Only the fertilizers that are actually mixed into the oil film affect oil biodegrdation. Fertilizing combined with land tilling does create a dry soil surface; however, rates of heterotrophic respiration are approximately the same as without this treatment. The use of sorbents without the addition of fertilizers did not enhance rates of respiration in this study.

The total decomposition rates during the second summer season are approximately 25 g oil/kg soil and 10 g oil/kg soil for aged and emulsified oil, respectively. These rates are comparable to other studies in the temperate zone, where rates between 9-165 g oil/kg soil were reported when oil content varied between 5% and 10% in the soil (Huddeleston, 1979).

The use of a solidifying agent created a non-sticky surface where the heterotrophic activity was greater than in the control plot. This treatment made it possible to manually pick up the oil from the soil surface. In this process, approximately 50% of the oil was removed from the surface. After removal of the solidified oil, total heterotrophic activity increased.

These studies show that, it is possible, by simple means, to enhance the oil biodegradation and restrict the negative environmental effects of oil even in the cold climate of arctic shorelines.

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